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Research Note

The optical counterpart of the IRAS point source 22343+7501 in L1251

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Abstract. We present the discovery of an optical counterpart of the extended bipolar CO outflow source observed by Sato and Fukui in L1251. Deep CCD images through [SII], Hα and continuum filters reveal a number of knots of different physical nature in the main body of the object. Two emission-line knots are probably Herbig-Haro objects. We recognized a further knot outside the main body which is well defined in [SII], much fainter in Hα and below the detection limit in the continuum. These emission line knots probably form a jet. We identified its driving source with IRAS 22343+7501 the supposed origin of the CO outflow.

Key words: Herbig-Haro objects – Interstellar medium: clouds: L1251 – Stars: pre-main-sequence

1. Introduction

L1251 is a small compact dust cloud (absorption class 5, surface area 0.195 sq.deg.) in Cepheus ($\alpha = 22^h35^m0$, $\delta = +75^o0'$), catalogued by Lynds (1962). The cloud probably belongs to an extended dust complex, known as 'Cepheus Flare'. However, this relationship needs further confirmation because of the lack of a reliable distance determination on this object. L1251 has been known as a strong OH emitting source since the advent of molecular radio astronomy (Cudaback and Heiles 1969). As Turner and Heiles (1971) pointed out the observed ratio of the OH emission lines is far from the value required by LTE. To account for this anomalous behavior they postulated a strong infrared source pumping the energy levels responsible for the observed OH emission. The cloud was also included in Dieter's (1973) list of sources observed in formaldehyd absorption against the microwave background. Kun (1982) discovered several emission line objects concentrated towards and within the optical boundaries of L1251. Their concentration towards L1251 provides further evidence that the cloud is a site of active star formation. Inspecting the POSS prints one can recognize several small nebulous objects in the optically less dense part of the cloud and near its boundaries. Neckel and Vehrenberg(1985) listed one nebulous object, GN22.28.3, lying close to the northern edge of the cloud; which we recognized as a faint spiral galaxy on our CCD frames (Kelemen et al. 1991). Cohen (1980) included one object in this area , RNO144, in his Catalogue of Red Nebulous Objects. More recently L1251 appeared among the objects of Zhou et al. (1989) in their CS survey of low-mass cores and among those of Benson and Myers (1989) surveying dense cores in dark clouds. The IRAS mission (Beichman et al. 1984) detected several point sources in this area. On the Sky Flux Maps of the extended emission the cloud displays two very bright cores at 60 and 100 μm. Both of them host a strong IRAS point source: 22376+7455 and 22343+7501, which were discovered as sources of bipolar CO outflows by Sato and Fukui (1989). In order to derive the distance of this region by detailed star count studies, we obtained several CCD frames in U, B, V, R and I colors at different positions in and around the cloud area . On the R and I frames taken at the position of the IRAS source 22343+7501 we recognized a conspicuous nebulosity consisting of an elongated 'S'-shaped diffuse component embedding several bright knots. The whole structure was at the limit of detection in the V band. With the aim of having insight into the physical nature of these structures we made narrow band CCD observations in the Hα and [SII] lines. The purpose of our present paper is to describe the main characteristics of this nebulosity.

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2. Observations

We observed this nebulous structure through Johnson V, R, and I filters using a CCD camera mounted at the Cassegrain focus of the Calar Alto 1.23 m telescope. The CCD was a GEC 8603A (coated) with 385 X 576 pixel of 22 x 22 μm^2 size yielding a scale of 0.46 arcsec/pixel. For narrow band imaging we used a CCD camera in the prime focus of the Calar Alto 3.5 m telescope. This camera was equipped with an RCA SID 006 EX CCD with 640 x 1024 pixels and a pixel size of 15 x 15 μm^2. It was binned by a factor of two giving a scale 0.5 arcsec/pixel.

For the narrow band images we used a Hα interference filter (λ_c = 6580Å, $FWHM$ = 100Å) including also the [NII] 6548/6584Å forbidden lines and a [SII] interference filter (λ_c = 6740Å, $FWHM$ = 70Å) including the [SII]6717/6731Å doublet. In addition to these two narrow band filters we also obtained CCD images with a red continuum broad band filter (λ_c = 7200Å, $FWHM$ = 800Å). Our observations are summarized in Table 1. All the frames were reduced using the standard MIDAS procedures.

Table 1. Log of CCD observations

Date 1990	Seeing (FWHM)	Exposure (sec)	Filter	Telescope
21/22 Sep.	1."8	1000	R	1.23 m
21/22 Sep.	1."8	1000	I	1.23 m
21/22 Sep.	2."0	1000	V	1.23 m
12/13 Nov.	1."0	1800	[SII]	3.5 m
16/17 Nov.	1."6	1800	Hα	3.5 m
17/18 Nov.	1."1	900	Hα cont.	3.5 m

3. Morphological properties

3.1. The main body of the nebula

The overall structure of the object appears as an 'S' shaped open spiral. The POSS red print shows a faint nebulosity slightly above the plate background in this region which is invisible on the blue print. The object is hardly visible on our V frame.Its brightest central part consists of several knots and condensations but their appearance in the three spectral regions differs significantly from one to another .

The knots may have different physical nature with respect to the sources responsible for their radiation. Moreover, different kinds of radiation (stellar radiation, reflection from dust, emission from shock excited gaseous material) may contribute to the total observed flux within one knot . Without a detailed spectroscopic study, however, it is not possible to investigate the true nature of the radiation. Furthermore, due to the unknown spectral distribution of these condensations one cannot carry out detailed surface photometry of the different structural features in terms of well calibrated photometric quantities. Fig1.a-c show the images of the nebula as seen through an Hα, [SII] and continuum filter, respectively, taken with the 3.5 m telescope. One can recognize several brighter knots in the main body of the nebula but not all of these knots appear in all our frames as separate objects. The most dominant source in all filter is the sharply peaked knot close to the western edge of the main body of our object. It appears to be the starting point of a chain of knots ending at the second brightest source in the continuum.

From all these objects two are very conspicuous (designated with A and B in Fig.1b.) in the [SII] and Hα frames compared to the continuum frame. This is typical of Herbig-Haro objects. The remaining condensations may be either stars or density enhancements of the dusty material of the nebula. We tried to separate the line emitting sources from the continuum dominated sources by removing the contribution of the continuous radiation from the total measurable flux in the [SII] and *Hα* frames. We determined the averages of the [SII]/continuum and Hα/continuum ratios and subtracted the corresponding continuum intensities multiplied with these averages from the [SII] and Hα frames. The [SII] frame corrected by this procedure is displayed in Fig.1d. One can infer from the figure that in addition to the two strong emission knots A and B there are other regions in the nebula with some excess line emission radiation. In contrast, some parts of the nebula which are very bright in the continuum are removed almost properly by this procedure indicating that they are either dust knots or stellar sources.

3.2. The jet

In the north-eastern direction far outside the main body at a distance of 35 arcsec from the source B there is another knot (C) which is very conspicuous in the [SII], much fainter in Hα, and fully absent in the continuum light. It is difficult to derive a reliable [SII]/Hα ratio because the knot is very close to the detection limit in Hα. Drawing a straight line across the two strong emission objects A and B the line nearly intersects this outer knot indicating a possible relationship with the two strong emission line objects in the main body of the nebula. Fig.2 shows the intensity profiles extracted along this line from the Hα, and [SII] frames and corrected for the continuum radiation. The alignment of the three knots and the gradual change of the [SII]/Hα ratio along the line extracted makes plausible the assumption that these knots relates to each other: they apparently form a jet.

4. Discussion

In the preceding paragraphs we recognized several structural details embedded in the extended diffuse main body of our object. Unfortunately, we do not have enough information to set up a coherent picture to integrate these objects into a reliable physical model and to discuss their relationship to the IRAS point source 22343+7501, supposed to be the driving source of the CO bipolar outflow discovered by Sato and Fukui. However, the morphological and photometric data enabled us to discuss some details that might be useful for further investigations.

4.1. Differences between the [SII] and Hα profiles of the jet

The three emission knots apparently forming a jet reveal a systematic trend in the excitation starting from the knot A where the [SII]/Hα ratio is close to 1, jumping abruptly to 2 at B, and reaches about 2.5 at the outer knot. There is an offset of about two pixels (1 arcsec) between the [SII] and Hα profiles which could not be accounted for by improper alignment of the frames. We checked the alignment of the frames based on the stars in the field and it was better than one pixel, so the displacement between the [SII] and Hα profiles seems to be real. The displacement between the [SII] and Hα photocenters was also observed by Bührke et al.(1987) in HH34 and Reipurth and Heathcote (1991) in the jet of HH46/47. Assuming shock processes associated with the formation and propagation of jets our value of [SII]/Hα > 2 in B, and in the outer knot requires that the [SII] emission arises in a very weak shock (see e.g. Hartigan et al. 1987) in these parts of the jet. In this view the shock responsible for the excitation of the knots is very weak at the north-eastern and much stronger at the south-western end of the jet where the [SII]/Hα ratio is near 1. Our data are not sufficient to study the physical properties of the jet in more details and its relation to the main body of the nebula. Spectroscopic observations and near infrared surface polarimetry (as in the case of the Serpens Reflexion Nebula by Warren-Smith et al. 1987 and Gomez de Castro et al. 1988) would be necessary to solve these problems.

4.2. Relationship to IRAS 22343+7501

Sato and Fukui assigned the point source IRAS 22343+7501 to one of the bipolar CO outflows they discovered in L1251. Considering the far infrared colors of the source at 12, 25, 60 and 100 μm they suggest that it is either a low-mass protostar

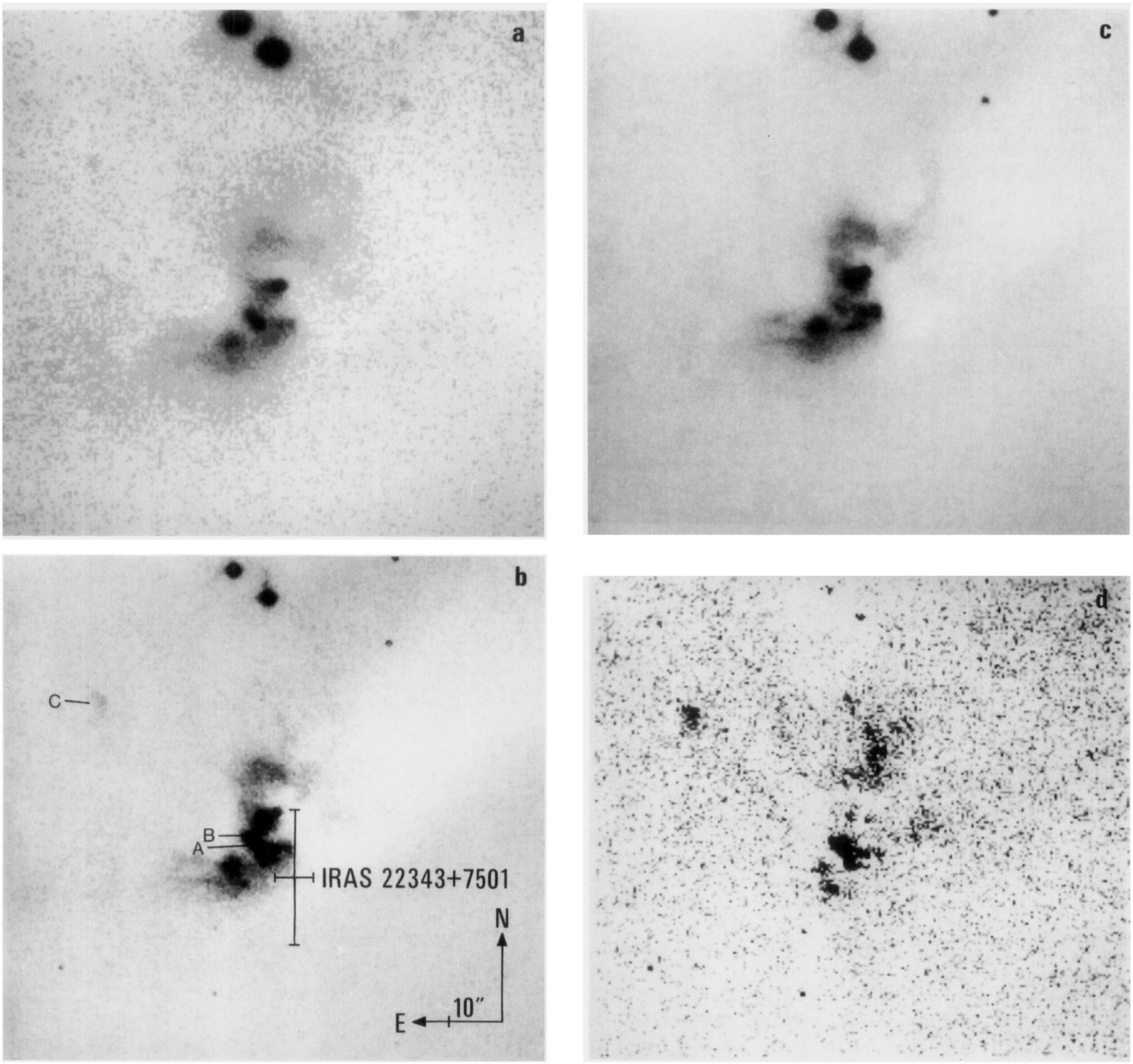

Fig. 1. a-c: The images of our object in Hα, [SII] and continuum, respectively, taken with the 3.5 m telescope. (North is at the top and east is at the left). Note the two bright knots (A and B) in the main body of the nebula and the outer knot (C), forming apparently a jet. The position of the IRAS 22343+7501 point source is also indicated. d: The image of the nebula in [SII] after correcting for the continuous radiation. Besides the three emission knots (A,B and C) some regions with excess of line emission are also present

or a very young low-mass star just passed through the protostar stage. The IRAS point source is close to the western edge of the main body as displayed in Fig.1b together with the error box given by Beichman et al. (1984). There is no remarkable condensation near the center of the error box. However, the center of the error box is aligned nicely with the jet. Within the error box one can find the second brightest source in the nebula. If it is really the driving source, then the jet would have suffered from a significant bending probably due to the encounter with a density enhancement in the nebula and changing its direction towards the outer knot. Although this might account for the the optical jet it fails to explain the coincidence with the axis of the CO outflow of Sato and Fukui. Namely, the bended direction has nothing to do with that of the counter lobe. The driving source has to be aligned with the jet and in this case it does not have an optical counterpart on our frames.

5. Summary and conclusions

– On deep R and I CCD frames taken with the Calar Alto 1.23 m telescope we recognized a faint 'S'-shaped nebulosity at the position of IRAS 22343+7501 identified as a possible

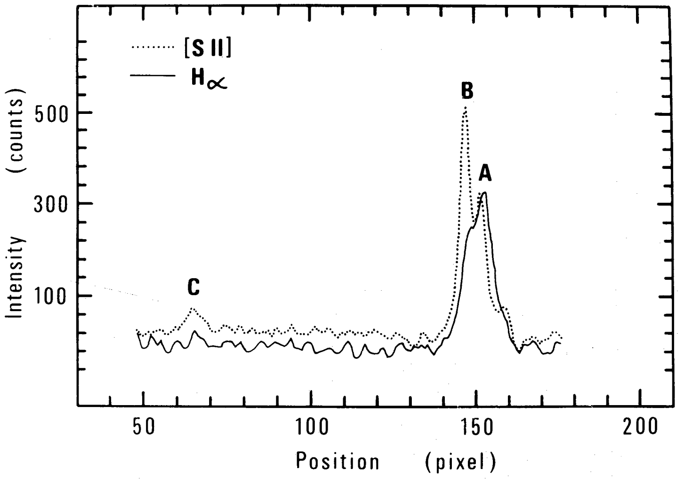

Fig. 2. The intensity profiles along the three line emitting knots in Hα and [SII] corrected for the continuum radiation. The alignment of the three knots and the gradual change of the [SII]/Hα ratio along the line extracted make plausible the assumption that these knots probably form a jet

driving source of an extended CO outflow by Sato and Fukui (1989).

- To get a deeper insight into its physical nature we obtained CCD images of the object with Hα/[NII], [SII] and continuum filters in the prime focus of the Calar Alto 3.5 m telescope and recognized several bright knots embedded in the main body of this nebulosity. Two of these bright knots are very strong in Hα and [SII] but invisible in the continuum; they are probably Herbig-Haro objects.
- Outside the nebula there is a further knot easily to recognize in [SII], much fainter in Hα and not detectable in the continuum. This outer knot is on the the line passing through the two emission knots on the main body. These three emission knots apparently form a jet.
- The intensity profiles of [SII] and Hα along the line joining these emission knots indicate that the excitation is the weakest at the outer knot and the strongest at the opposite end of the jet.
- We point out that the direction of the optical jet coincides very well with the alignment of the CO bipolar outflow discovered by Sato and Fukui (1989). We suggest that the driving source of the optical jet is probably the IRAS 22343+7501 point source, as suggested by Sato and Fukui in the case of the CO bipolar outflow.
- Our data are not sufficient to study the physical properties of the jet in more details and its relation to the main body of the nebula. Spectroscopic observations and near infrared surface polarimetry would be necessary to solve these problems.

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